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TITLE: LAMINATED PIEZOELECTRIC ACTUATOR

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ABSTRACT:

PURPOSE: To improve strength against mechanical impact by baking metallic paste containing glass frit of borosilicate zinc/lead series glass uniformly onto the opposite end faces and the edge sections of a laminated ceramic.

CONSTITUTION: Metallic paste containing glass frit of borosilicate zinc/lead series glass having thermal expansion coefficient approximately equal to that of a piezoelectric ceramic constituting a piezoelectric actuator is baked onto a pair of ceramic faces 11a, 11b crossing perpendicularly with the laminating direction of inner electrodes 12a, 12b and onto the edge sections 10a, 10b

located closely to the ceramic faces 11a, 11b thus obtaining a metallized structure. When the metallic paste is baked and metallization is carried out, glass frit in the paste is dispersed into the porous piezoelectric ceramic thus filling the porous layer with glass and metallic layer. Consequently, strength against mechanical impact is improved for the ceramic faces 11a, 11b and the edge sections 10a, 10b at the opposite ends of the actuator.

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TITLE: Ceramic bonding method

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A method for coating a ceramic with a strong, adherent, substantially defect-free, and thermomechanically shock resistant metallized layer for practical use at over 630.degree. C. comprising selecting a ceramic metallizing composition; preparing the composition by proportioning the differing sizes of the mixed ingredients to have gravitationally substantially nonsegregating qualities when applied onto said ceramic; coating the ceramic with the metallizing composition; heating the coated ceramic surface to achieve ceramic metallization; and keeping the composition molten sufficiently long time to form the required metallized layer.

In FIG. 1, a system for real-time monitoring of the settling particles employed to determine the starting time for collecting the residual or still unsettled mixed particles to be used for metallization. This system has a vertical settling cylinder 10. Near the bottom of the cylinder 10, two pairs of light emitters 11 and detectors 12 are located at two different heights with emitters on one side and detectors on the opposite side of a vertical cylinder 10, to sense the settling particles. The times for the particles to pass the top or bottom emitter/detector pair determine the particle size or type being monitored, while the times for the particles to transverse

through the vertical distance d between the heights give their velocities. When the settling velocities of the two types (and sizes) of the powders are within a specified percentages, a slide shuttle 14 is moved to catch on the shuttle the residual or unsettled mixed powder of nearly equal settling velocities. These equal-settling mixed powders in suspension are separated for immediate metallizing use while the already settled powders are drained through the valve 15 for subsequent reuse.

To completely eliminate gravitational segregations, solution metallizing is the ideal process. Many molybdenum and tungsten compounds are soluble in water, alcohol, acid, or bases. MoO<sub>3</sub>, for example, is soluble in hot or ammoniated water. Oxide, chloride, nitrate, sulfate, halogen, and other compounds of iron, manganese, nickel, antimony, lead, tin, copper, zinc, and bismuth are similarly soluble. Mixtures of W/Mo and the other solutions may be compounded into proper compositions for the metallization of various ceramics.

The use of solutions of compounds, e.g., halides, of nickel, lead, tin, zinc, and copper allow these metal compounds to be reduced in a hydrogen or nitrogen/hydrogen atmosphere to supply the braze metal. In a single processing step, then, complete metallizing, brazing, and bonding is possible.

The ceramic I have already bonded with my W/Mo-based metallizing methods described here include: diamond, alumina, zirconia, silicon carbide, beryllia, yttria, graphite, quartz, silicon, mullite, cordierite, Corning's MACOR and Vision glass, piezoelectric ceramics, graphite-aluminum composites, carbon-carbon composites, and 123 high-temperature

superconductors. Useful structural metals for the joints include copper, nickel, stainless steel, high-nickel or cobalt iron alloys, or even highly "mismatched" ordinary cold-rolled SAE 1010 carbon steel. Even with the "mismatch" between ceramic and carbon steel, structural joints brazed with pure copper can be repeatedly thermal cycled without fractures between 980.degree. C. (i.e., about 100.degree. C. below the melting point of copper braze) and ice water followed by mechanical shocks including 8 to 10-foot drop tests onto carpeted, wood, or even marble floors.

A most common method of metallization in semiconductor contacting, or for bonding diamond to copper for diamond heat sink application, consists of first sputtering a layer of 600 Å titanium, followed by 1,200 Å of platinum and one micron of gold. The titanium bonds to the diamond, while the gold bonds to the metal. The platinum is a diffusion barrier to prevent interaction between titanium and gold. The preparation of an diamond heat sink for electronic circuits requires four Ti-Pt-Au-bonding processing steps for bonding top or bottom surfaces of the diamond. The entire bonding process, requiring eight critical processing steps, is thus costly, complicated, and degrading to the product. Still, the product often fails because of peeling, blistering, intermetallic formation, and unwanted reaction between different phases.

The many complex and costly Ti-Pt-Au-bonding processing steps present formidable challenges that have so far failed all materials scientists worldwide. Thermochemical instability may render the Ti-Pt-Au-Cu system unreliable. The National Materials Advisory Board

concluded in 1990 that metallization will be "the predominant failure mechanism" in future diamond electronics. See attached copy of the relevant portion of the DTIC Report Ad-A222,986, p. 81.

7) Preages and burns-in the metallization contacts, which is the predominant failure mechanism of hard semiconductors (SiC, diamond).

Indeed, my diamond metallizing processing steps fully stabilizes, preages, and burns-in the diamond and, therefore, generates very reliable metallization contacts. Reliable contacts is important because metallization has been considered to be the predominant failure mechanism of reliable diamond electronics. There will also be no dopant outdiffusion and redistribution, because of the thermodynamic equilibrium of constituents even at the high metallizing/doping temperatures. This is in sharp contrast to ion implantation and other doping methods, where the dopant atoms are barbarously forced into the semiconductor with high voltage and momentum, with highly unstable results even at low temperatures.

This proven simplified processing technique combines the metallizing, brazing, contacting, and high-temperature pre-aging or burning-in steps into one operation. The pre-aged or burned-in connections overcome the predominant failure mechanism in diamond electronics due to improper metallization. For diamond active semiconductors, or diamond heat sink applications in electronic circuits, the microscopically perfect wetting and bonding of diamond by metal maximizes contact area, thermal conductivity, and conductance. The single-phase low-modulus or dead-soft annealed braze absorbs mismatch stresses

and strains, assuring high thermomechanical shock resistance and uniform, stable carrier mobilities and predictable circuit characteristics.

When molybdenum is used as the metallized layer together with an osmium, rhenium, platinum, protactinium, rhenium, and tantalum braze layer, the melting point of molybdenum, i.e., 2810.degree. C., rather than that of the braze layer, generally limits the useful temperature of the joint. Similarly, when tungsten (melting point 3410.degree. C.) and carbon (melting point 3650.degree. C.) are used as the metallized and brazed layers for more refractory materials, respectively, the lower tungsten melting point dominates. A variety of new, metallized fibers or particulates of, e.g., SiC, Si<sub>3</sub>N<sub>4</sub>, Al<sub>2</sub>O<sub>3</sub>, ZrO<sub>2</sub>, mullite, cordierite, diamond, glass, quartz, and other ceramics can thus be produced that can be used as reinforcement in composites for temperatures over 1500.degree., 2000.degree., 2500.degree., 3000.degree. C., or higher.

Chemical reactions between the matrix and reinforcement are serious problems in composites. In graphite-aluminum composites, for example, the graphite reinforcement may react with matrix aluminum to form brittle aluminum carbide. At a given service, processing, or other operating temperature over about 800.degree. C., the graphite-aluminum interfacial reactions may thus be intolerable. High-melting metals given above and used as the metallized/brazed layers on the graphite slow down the elemental diffusion rates and, therefore, graphite particulate- or fiber-matrix interfacial reactions. The heavy metals W or Mo and refractory metals slow down even further. This is because the

elemental diffusion rates are functions of the ratio of the operating temperature to the absolute melting temperature. At the same operating temperature of, e.g., 550 C., this ratio for aluminum directly contacting graphite is  $(550+273.1)/(660.4+273.1)=0.882$ . With nickel braze on the graphite fibers according to my invention, the interfacial reaction is now between nickel and graphite, and the same ratio is reduced to  $823.1/(1455+273.1)=0.476$ . When the graphite fibers are metallized with Mo or W, the same ratios are further reduced to 0.267 or 0.223, respectively. With a wide variety of available metallizing alloys (e.g., W-Fe, Mo-Mn, . . .) and coated layers on ceramic reinforcing fibers and particulates, these ratios can be selectively chosen to be less than, e.g., 0.6, 0.5, 0.4, 0.3, 0.22, or even less. The matrix-reinforcement interfacial chemical reactions are thereby reduced, weakening of composite strength is minimized and embrittlement of reinforcement or destruction of composite avoided.

Interfacial chemical reactivity between, e.g., ceramic reinforcement and the metal matrix, can be further suppressed or totally eliminated by coating the metallized/brazed layer with chromium or aluminum. Chromium, aluminum, and their alloys form adherent, dense oxides that resist further oxygen penetration to, e.g., the underneath graphite fibers. These specially metallized/coated graphite or carbon fibers are thermochemically stable in oxygen or other oxidizing atmospheres.

Even mismatch ceramic-metal joints made according to my invention refused to fail under repeated, rapid and severe thermomechanical shocks. Further, the final forced fractures occur away from the bonding regions.

This shows that the bonds are free of flaws, microcracks, inclusions, and other defects. In addition, the bond is actually stronger than the weaker ceramic member. This is because the liquid layer formed on the ceramic surface during the metallizing step, generally from 5 to 50 microns thick, actually seals surface notches and other flaws. The metallizing W/Mo ingredients, from examination of microphotos, also strengthen the ceramic at the interfacial region through solution strengthening, or formation of microcomposite reinforcement in the form of precipitated particulates and reinforcing roots, branches, or networks.

Another problem with composites is that ceramic, graphite, and carbon fibers are very difficult to be perfectly wetted by, or bonded to, metals, other ceramics, or even to epoxy. Because of this difficulty, an airplane or other vehicle made of these composites often structurally fails under cyclic environmental heat-moisture conditions. Under capillary attraction forces, rain or condensed moisture on the composite surface deeply penetrates, or is sucked in, along the tiny passageways in the unbonded or poorly bonded interfacial regions between the graphite or other ceramic fibers and the epoxy, metal, or ceramic matrices. This penetration is facilitated by air release in, for example, an improperly oriented one-dimensional reinforcement where water enters from the outside skin and move freely along the entire length of the fibers, with entrapped air being forced to leave out of the inner surfaces. This fills the composite structure with water. When the environment turns cold, the filled water expands on freezing, disruptively enlarging the passageways and further debonding the reinforcement from

the matrices.

Repeated filling-expanding cycles may destroy the composites. When a high-altitude airplane lands in a hot humid weather, moisture automatically condenses onto the very cold composite skin and similarly fill the passageways.

The vehicle may take off again into the same freezing attitude where the filled water expands on freezing with disruptive forces. Multiple cycles of landing and high-altitude flying also destroy the composite.

Using my metallizing methods described above, metallized refractory metallic compounds can be formed for uses as the matrix or reinforcement for composites.

These compounds include: oxides of Al, Ba, Be, Ca, Cr, Eu, Gd, La, Mg, Ni, Pu, Ru, Sm, Sc, Si, Th, Ti, U, V, Y, and Zr; carbides of Al, B, Ba, Be, Ca, Hf, Mo, Nb, Si, Ta, Th, Ti, U, V, W, and Zr; borides of Ba, Ca, Ce, Hf, Mo, Ni, Sr, Ta, Th, Ti, U, V, and Zr; Sulfides of Ca, Gd, Sr, U, and Y; nitrides of Al, Hf, La, Nb, Nd, Sc, Si, Pr, Pu, Ta, Th, Ti, U, V, Y, and Zr; and aluminides of Fe, Ni, Pt, Be, and Ti. Particularly attractive among these compounds are: Si.<sub>3</sub>N<sub>4</sub>, Si<sub>3</sub>Al<sub>2</sub>O<sub>5</sub>, SiC, Al<sub>2</sub>O<sub>3</sub>, mullite, AlN, B<sub>4</sub>C, TiB<sub>2</sub>, and BN.

Light, strong, tough, and reliable structural Al, Mg, Be, Ti alloys in composite forms can thus be made with metallized graphite, SiC, or other ceramic reinforcement that will operate over 480 degree C.

Preferably, these penetrating metallizing material form reinforcement in a matrix of the ceramic material at the interfacial region. This can be achieved by selecting a W/Mo-based metallizing composition which, with the ceramic at the metallizing temperature, forms hard (Mohr hardness over

8 or 9 versus less than 7 or 6 for the matrix), tough, and strong compounds. Useful compounds include PbMoO<sub>4</sub>, MgWO<sub>4</sub>, CaMoO<sub>4</sub>, MnWO<sub>4</sub>, MnMoO<sub>4</sub> and the like. In practice, I simply use pure starting materials such as MoO<sub>3</sub>, WO<sub>3</sub>, PbO, CaO, . . . , prepare the exact or near stoichiometric compositions for the metallizing compositions, and metallize at a temperature 50.degree. to 200.degree. C. above the melting points of these compounds. By varying the metallizing time, the grain-boundary reinforcing compounds penetrate to different depths, according to the square root of time diffusion law. For example, for a liquid diffusion case with a diffusion coefficient of 10E-5 cm.times.cm/sec, metallizing for 5 to 60 minutes gives a diffusion length or penetration depth of about 0.055 to 0.19 cm. The required liquid metallizing times are 30.2 and 361 seconds, respectively, if a liquid diffusion coefficient of 10.<sup>-4</sup> cm.<sup>2</sup>/sec is used. If the liquid diffusion coefficient of 10.<sup>-5</sup> cm.<sup>2</sup>/sec is chosen, the required metallizing times are 302 and 3,610 seconds, respectively. I also achieved moderately different penetrations of reinforcing particles, fibers, or sheets of different penetration depths by changing the metallizing compositions, e.g., from the W-based type to the Mo-based type.

As shown in FIGS. 4b-4d, the molten metallized/brazing materials of the metallizing composition not only form the metallized bonding layer to join ceramic to form bonded ceramic structures, but also penetrate along the ceramic grain boundaries to form three-dimensional metallic reinforcement in the form of fibers, sheets, branches, particles, roots, or net works. The reinforcement

is strengthening to the ceramic if the metallizing/brazing material is relatively hard, such as the various reinforcing compounds of WO<sub>3</sub> or MoO<sub>3</sub>, but toughening is the same materials are ductile such as Cu, Al, Mg,

The metallic reinforcement fibers, sheets, networks, and branches additional define the ceramic grains and completely (FIG. 4d) or partially (FIGS. 4b and 4c) separate the ceramic grains. These soft and ductile ceramic grain boundary materials absorb thermomechanical shocks, making the ceramic less brittle. Through yielding and stress absorption, the thermal mismatch stresses and strains are localized within the enclosed ceramic grain, and cannot transmit to neighboring grains, at least not with full force. These metallic reinforcement thus acts as shock absorbers, stress and strain isolators, and ceramic strengtheners or toughners.

3. A method as in claim 1 comprising the additional step of forming, with the molten metallizing composition, microcomposite reinforcement in the surface region of the at least first ceramic.

4. A method as in claim 3 wherein said forming step comprises forming a microcomposite reinforcement in the at least first ceramic.

5. A method as in claim 4 wherein said forming step comprises forming said microcomposite reinforcement in an elongated form selected from the group consisting of fibers, roots, lamella, and weaves; positioning the elongated reinforcement to originate from a peripheral edge of the first ceramic at the bonding interfacial surface and extending into the body of the first ceramic; and

at the peripheral edge orienting the elongated reinforcement at 45 .degree. to the bonding interfacial surface.

6. A method as in claim 4 wherein said forming step comprises forming said reinforcement to have a Mohr hardness of at least 8.

7. A method as in claim 4 wherein said forming step comprises forming in the at least first ceramic said reinforcement in a form selected from the group consisting of:

8. A method as in claim 4 wherein said selecting and preparing step comprises selecting the metal from the group consisting of W and Mo, said metallizing composition forming, at the metallizing temperature, the reinforcement in the form of a reinforcing compound of the selected metal, and comprising the additional step of:

said metallizing composition, when heated to a metallizing temperature at which the first ceramic is metallized, being capable of reacting with said bodies to form a highly wettable metallized bonding layer for joining said bodies together, said metallized bonding layer containing said metallic substance in the form of a metallic reinforcement for the first ceramic; said metallic reinforcement being selected from the group consisting of a ceramic strengthener and a ceramic toughener;

upon cooling, said metallized bonding layer joining the bodies together to form said bonded ceramic structure and providing said metallic reinforcement for reinforcing the first ceramic body material.

39. A method as in claim 35 wherein the solid bodies are the ceramic grains in

the interfacial bonding region of a ceramic joint and including the additional step of dispersing, through a selected manufacturing step according to a specified design rather than through incidental unplanned dispersing procedures, said metallic reinforcement in the form of a three-dimensional microcomposite reinforcement in said bonded ceramic grains.

40. A method as in claim 35 wherein said metallic substance consists essentially of a ductile metal or alloy and wherein the solid bodies are ceramic bodies and including the additional step of dispersing, through a selected manufacturing step according to a specified design rather than through incidental unplanned dispersing procedures, said metallic reinforcement in the ceramic bodies in the form of a network of ductile metallic reinforcement thereby toughening the ceramic bodies.

41. A method as in claim 35 wherein at least a majority of the solid bodies are ceramic bodies and including the additional step of dispersing, through a selected manufacturing step according to a specified design rather than through incidental unplanned dispersing procedures, said metallic reinforcement among the ceramic bodies in the form of a three-dimensional microcomposite reinforcement.

42. A method as in claim 41 wherein the solid bodies are ceramic bodies and including the additional step of dispersing, through a selected manufacturing step according to a specified design rather than through incidental unplanned dispersing procedures, said metallic reinforcement among all the ceramic bodies in the form of a network of said metallic reinforcement comprising a ductile metal or alloy.

partially or completely connecting the neighboring regions to each other with said metallic reinforcement.

44. A method as in claim 43 wherein said metallic reinforcement comprises said metallic substance in the form of a ceramic toughener capable of absorbing stresses and strains, and including the additional steps of:

defining and partially or completely physically separating the neighboring regions with said metallic reinforcement; and

absorbing within said reinforcement the thermal mismatch stresses and strains in the thus-defined regions to minimize the transmission of these mismatch stresses and strains from any one of said regions to its neighbors thereby toughening the first ceramic body.

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⑪発明の名称 積層型圧電アクチュエータ

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## 明細書

## 1 発明の名称

積層型圧電アクチュエータ

## 2 特許請求の範囲

1. 圧電性セラミックス焼結体に互いに対向する複数の内部電極層を積層し構成した積層型圧電アクチュエータにおいて、内部電極積層方向と直交する両端のセラミックス面と該セラミックス面の縁部を、圧電性セラミックス焼結体とほぼ等しい熱膨張係数を有する矽酸亜鉛・鉛系のガラスフリットを1~20重量部を含有する金属ペーストにより、メタライズされた構造とすることを特徴とする積層型圧電アクチュエータ。

## 3 発明の詳細な説明

## イ. 発明の目的

[産業上の利用分野]

本発明は、電気エネルギーを受けると該電気工

エネルギーに比例して、変位や力の機械エネルギーに変換する積層型圧電アクチュエータに関し、特に複数の対向内部電極層を有する一体焼結型の積層型圧電アクチュエータに関する。

## 【従来の技術】

従来、精密位置決め装置や、精密X-Yテーブルのアクチュエータとして、ボイスコイルモータやパルスモータ等の電磁式アクチュエータが使用されていたが、近年、位置決め精度の高精度化、応答速度の高速化、低消費電力等の要求から、前記電磁式アクチュエータに比べて優れた特性を持つ積層型圧電アクチュエータが使用されつつある。積層型圧電アクチュエータは製造技術の進歩により、その変位方向に直交する圧電セラミックス板の断面積と、圧電セラミックス板の間に積層して設けてある内部電極の断面積を一致させる構造とすることにより応力集中を無くし、発生する歪量を大きくする事が可能となった。

第2図は従来の積層型圧電アクチュエータ<sub>2</sub>を示すが、圧電性セラミックス焼結体<sub>3</sub>を挟んで対

向する内部電極12a, 12bを設け、圧電性セラミックス焼結体3と内部電極を積層して形成し、内部電極12a, 12bの積層方向に直交する一对のセラミックス面11a, 11bと、対向する電極端面を電気絶縁するためのガラス絶縁部13、内部電極12a, 12bに夫々接続する外部電極14(一方の外部電極は図示せず)等から構成される。又、積層型圧電アクチュエータの電気絶縁を確保する為、前記セラミックス面11a, 11bを除く周囲四面は、通常有機系樹脂層(図示せず)で外装する。一方、積層型圧電アクチュエータの変位量はミクロンの単位であり微少なので、変位方向の寸法も高精度が要求され、製造の工程で前記セラミックス面11a, 11bを改めて機械加工により寸法出しが一般的である。

#### [発明が解決しようとする課題]

しかしながら、積層型圧電アクチュエータを位置決め装置やX-Yテーブルへ組込む際には、内部電極積層方向に直交する一对のセラミックス面を利用して、接着等により固定するのが一般的であるが、該セラミックス面が機械的衝撃に対する強度が弱く、特にセラミックス面の縁部へ応力が集中し易く、セラミックス面の縁部が割れ易いという問題がある。

本発明は、機械的衝撃に対して強度が充分で、セラミックス面にひび割れや、セラミックス面の縁部での割れの発生のない積層型圧電アクチュエータを提供することにある。

#### ロ. 発明の構成

##### (課題を解決するための手段)

本発明は、互いに対向する複数の内部電極層を有する積層型圧電アクチュエータにおいて、内部電極積層方向に直交する一对のセラミックス面と該セラミックス面に近接する縁部に、圧電アクチュエータを構成する圧電セラミックスと熱膨張係数がほぼ等しい硼硅酸亜鉛・鉛系ガラスのガラスフリットを含む金属ペーストを焼付け、メタライズした構造とすることを特徴とする積層型圧電アクチュエータである。

即ち本発明は、圧電性セラミックス焼結体に互いに対向する複数の内部電極層を積層し構成した

積層型圧電アクチュエータにおいて、内部電極積層方向と直交する両端のセラミックス面と該セラミックス面の縁部を、圧電性セラミックス焼結体とほぼ等しい熱膨張係数を有する硼硅酸亜鉛・鉛系のガラスフリットを1~20重量部を含有する金属ペーストにより、メタライズされた構造とすることを特徴とする積層型圧電アクチュエータ。

#### [作用]

本発明による積層型圧電アクチュエータは、内部電極の積層方向に直交する両端面のセラミックス面の表面及び近接する縁部を、熱膨張係数が積層型圧電アクチュエータを形成する圧電セラミックスとほぼ等しい特性を有する、主成分が硼酸と、硅酸と、酸化亜鉛と、酸化鉛とから成る硼硅酸亜鉛・鉛系ガラスのガラスフリットを含む金属ペーストでメタライズするものである。従って金属ペーストを焼付けしてメタライズを行う際、ペースト中のガラスフリットが、本来多孔質である圧電セラミックスの内部へ拡散して多孔質層をガラス及び金属層で充填し、積層型圧電アクチュエータ

両端のセラミックス面、及びセラミックス面に続く縁部の機械的衝撃に対する強度を向上するものである。

本発明に使用する積層型圧電アクチュエータの両端面に形成するメタライズ層のガラスフリットに用いるガラスは、熱膨張係数が圧電性セラミックス焼結体とほぼ同じ熱膨張係数を持つガラスで、硼酸が15~25重量部、酸化亜鉛が40~60重量部、酸化鉛が2~10重量部、酸化ビスマスが0.1~5重量部、残硅酸から成り、前記組成の範囲の組合せにより圧電セラミックス焼結体の熱膨張係数とほぼ等しい値を持つ熱膨張係数のガラスとする。又鉛に対するガラスフリットの比率も1~20重量部である銀ペーストを用いるが、銀の中に含まれるガラスフリットの量が1重量部以下では、ガラスは圧電性セラミックス焼結体に対する糊の役割を果たさず、又20重量部以上ではガラスの特性が強くなり、ひびの発生が出易くなる。

#### [実施例]

以下、本発明の実施例を、より詳細に説明する。

第1図に示す本発明に係る積層型圧電アクチュエータ上は、モル%比でPb<sub>[(Ni<sub>0.15</sub>·Nb<sub>0.35</sub>)Ti<sub>0.35</sub>·Zr<sub>0.15</sub>]O<sub>3</sub>系圧電セラミックスを出発原料として厚膜積層法により作られ、断面が5mm×5mm、長さが18mmの寸法の積層型圧電アクチュエータである。内部電極12a, 12bの材料は、銀-パラジウム合金を用い、内部電極12a及び12b間の間隔は115μm、内部電極積層数は150である。外部電極14はガラスフリット入りの銀ペーストを焼付けて形成してある。</sub>

次いで、この積層型圧電アクチュエータの内部電極積層方向に直交する両端面のセラミックス面11a, 11bと、該セラミックス面に近接する縁部10a, 10bに硼硅酸亜鉛・鉛ガラスが4重量部のガラスフリットを含む銀ペーストを塗布乾燥後、550°Cで30分熱処理焼付けし、メタライズした。

本発明に用いたガラスフリットは、ガラスの熱膨張係数が圧電性セラミックス焼結体とほぼ同じ値を持つ、酸化亜鉛50重量部、酸化鉛5重量部、酸化ビスマス1重量部、硼酸15重量部、硅酸が残

重量部のガラスフリットを用い、第1図のハッチングで示す部分にメタライズ層を形成した。メタライズ層の厚みは、1~2μm, 10~15μm, 50~60μmの3種につき実施した。しかる後に、本発明の実施例の積層型圧電アクチュエータの機械的衝撃に対する強度を調査する為、メタライズした縁部10a, 10bに、厚みが0.5mm、幅が20mm、長さが50mmの鋼板を用い、鋼板の厚さ部分が衝突する様に繰り返し縁部に衝撃試験を実施した。繰り返しの衝撃回数は1回当たりの試験で10回実施し、衝撃位置を変えて10箇所ずつ試験を実施した。比較の為、従来構造の積層型圧電アクチュエータについても同様の試験を実施した。試験結果を第1表に示す。

以下余白

第1表 【割れの発生の有無】

衝撃位置 メタライズ厚さ		1	2	3	4	5	6	7	8	9	10	計
本発明による アクチュエータ	1~2ミクロン	有	有	有	無	有	有	有	無	有	7箇所	
	10~15ミクロン	無	無	無	有	無	無	無	無	無	1箇所	
	50~60ミクロン	無	無	無	無	無	無	無	無	無	0箇所	
比較例	—	—	有	有	有	有	有	無	有	有	9箇所	

第1表に示す割れは、割れの長さが0.5mm以上、深さ50ミクロン以上のものを割れとし計測した。

第1表より明かな様に、比較例の従来の積層型圧電アクチュエータは10箇所中9箇所に割れの発生が認められるが、本発明による積層型圧電アクチュエータでは、メタライズの厚みが10μm以上の時は1箇所のみの割れの発生が認められるのみであり、本発明の実施例により機械的衝撃に対する強度向上が認められる。尚、本発明の実施例の金属は銀を用いた例で示したが、銀以外の、金、白金、又は銀とこれ等金属との合金を用いてもよく、金属ペーストを圧電性セラミックスにメタライズ

する時の焼付け時のガス雰囲気を非酸化性雰囲気で行う時は、金属として、ニッケル、又は銅を用いても本発明と同じ効果が得られる事は当然である。

#### ハ. 発明の効果

##### 【発明の効果】

以上説明したように、本発明の積層型圧電アクチュエータは、積層したセラミックスの両端面及び端面の縁部に、均一に硼硅酸亜鉛・鉛系ガラスのガラスフリットを含む金属ペーストを焼付けした構造の積層型圧電アクチュエータであり、機械的衝撃に対する強度の向上がなされ、より高品質の積層型圧電アクチュエータの提供が可能となり、応用分野の拡大が計れる。

#### 4 図面の簡単な説明

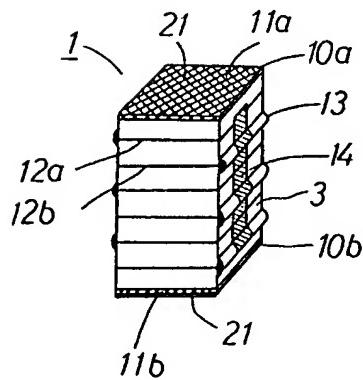
第1図は、本発明による積層型圧電アクチュエータの斜視図。

第2図は、従来構造の積層型圧電アクチュエータの斜視図。

1…本発明の積層型圧電アクチュエータ、2…従来の積層型圧電アクチュエータ、3…圧電性セラミックス焼結体、10a, 10b…縁部、11a, 11b…セラミック面、12a, 12b…内部電極、13…ガラス絶縁部、14…外部電極、21…メタライズ部。

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第1図



第2図

